

## **REMARKS**

Reconsideration of this application, as amended, is requested.

Claims 5-7 remain in the application. Claims 1-4 were canceled previously.

Claim 8 now has been canceled and is being prosecuted in a divisional application.

Claim 5 was rejected under 35 USC 112, second paragraph. The Examiner asserted that claim 5 was interpreted as defining features of the diesel engine and not features of the common-rail injection system.

Claim 5 has been amended to address the rejection under 35 USC 112.

Claims 5-7 were rejected under 35 USC 102(b) as being anticipated by U.S. Patent No. 5,979,945 to Hitachi et al. The Examiner correctly noted that the Hitachi et al. reference is directed to a common-rail injection system for a diesel engine. The Examiner explained accurately that Hitachi et al. has a main pipe rail with an axial-extending circumferential wall with an inner circumferential surface defining an axial flow passage through the main pipe rail. The Examiner further noted correctly that at least one branch hole extends through the axially extending circumferential wall of the main pipe rail for communication with the axial flow passage of the main pipe rail. The Examiner then asserted that the main pipe rail of the Hitachi et al. reference is "formed from a transformation induced plastic type strength steel, at least portions of which have been processed into residual austenite." The Examiner asserted that the residual austenite is at least at locations adjacent the branch hole and the inner circumferential surface. The Examiner then asserted that the Hitachi et al. reference teaches a compression residual stress defined in the axially-extending circumferential wall of the main pipe rail at locations adjacent the inner circumferential surface and surrounding the branch hole for defining a

process induced martensite at those locations. The Examiner further stated that the previous Amendment asserted that there were differences between the subject invention and Hitachi et al. However, the Examiner concluded that the remarks in the previous Amendment did not define the differences, and hence the Examiner concluded that there were no differences.

As noted previously, the Hitachi et al. reference is assigned to the assignee of the subject invention, and hence the assignee is very familiar with the teaching of Hitachi et al. The assignee respectfully disagrees with the above-quoted conclusions in the final rejection. In any event, claim 5 has been amended to distinguish further over Hitachi et al. The Hitachi et al. common rail clearly is formed from stainless steel (see col. 4, lines 39-41). Amended claim 5 defines the main pipe rail of the subject invention as being formed from "a transformation induced plastic type strength steel with substantially no stainless steel." Amended claim 5 also defines the transformation induced plastic type strength steel of the main pipe rail as having "a residual austenite at least in a layer of the main pipe rail adjacent the inner circumferential surface." Amended claim 5 further defines a compression residual stress "in the axially-extending circumferential wall of the main pipe rail at locations surrounding the branch hole therein for defining a process induced martensite at said locations." Austenite is a phase in certain steels that typically is stable only above a relatively high temperature (e.g., 1333°F). However, as austenite cools this structure either breaks down into a mixture of ferrite and cementite or undergoes a lattice distortion known as martensitic transformation. The rate of cooling determines the relative proportions of these materials and therefore the mechanical properties of the steel. Other metals, such as manganese or nickel may be added to the steel to stabilize the austenitic

structure for certain applications. The transformation from austenite to martensite may be incomplete, and the remaining cooled austenite is referred to as residual austenite. This residual austenite may remain unchanged at room temperature together with the martensite. The presence of residual austenite is considered a defect in many products. In this regard, this Amendment is submitted concurrently with publications that consider residual austenite. For example, the attached article in the Institute of Precision Mechanics suggests that residual austenite indicates defects in the form of low hardness. The attached article entitled X-Ray Diffraction suggests that even a small percentage of residual austenite can cause deformations that make the piece unusable. This publication refers to a detected presence of residual austenite in injector pins for diesel motors.

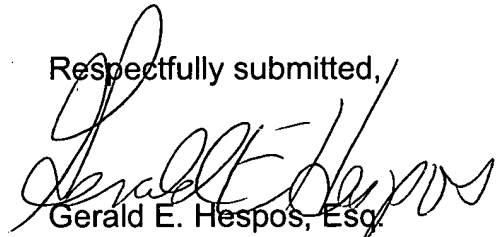
Counsel appreciates that some of the language in original claim 5 employed process terminology. However, amended claim 5 includes clear structural limitations. In this regard, claim 5 specifies that the residual austenite is "at least in a layer of the main pipe rail adjacent the inner circumferential surface." Claim 5 also specifies that a "compression residual stress" is defined in the axially extending circumferential wall of the main pipe rail so that "a process-induced martensite exists at said locations surrounding the branch hole." These are all physical characteristics and not process limitations.

The assignee's earlier Hitachi et al. reference is a stainless steel common rail and there is no suggestion of a TRIP steel "with substantially no stainless steel and with "residual austenite", as set forth in amended claim 5. These are very significant differences that affect processability at a forging time (page 7, last line). This distinguishes from the prior art that has little or no residual austenite. Such prior art is not easily deformed and is not easily cut, as explained in the specification. The enhanced

deformation permitted with the claimed main pipe rail reduces the number of pipe extending steps that are required to achieve the necessary formation of the common rail. Thus, processing time and cost can be reduced and a smaller forming machine can be employed. Additionally, the process-induced martensite at locations surrounding the branch hole improves both hardness and tensile strength at the critical locations surrounding the branch hole. Thus, the residual austenite ensures efficient processing of the main pipe rail and the process-induced martensite has very desirable strength and hardness characteristics. It is also submitted that the assignee's earlier stainless steel common rail does not teach or suggest the limitations of amended claim 5.

The Examiner is urged to contact applicants attorney at the number below to expedite the prosecution of this application.

Respectfully submitted,



Gerald E. Hespos, Esq.

Atty. Reg. No. 30,066

Customer No. 001218

CASELLA & HESPOS LLP

274 Madison Avenue - Suite 1703

New York, NY 10016

Tel. (212) 725-2450

Fax (212) 725-2452

Date: September 22, 2005

**BEST AVAILABLE COPY**

NDT.net - December 1998, Vol. 3 No. 12



Table of Contents ECNDT

'98

Session: Steel

## Determining Residual Austenite With the Eddy Current Method

C. Dybiec, A. Kozłowska

Institute of Precision Mechanics, UL. Duchnicka, 00-967 Warszawa  
Deawoo FSO sp. z o.o., UL. Jagielonska, 03-215 Warszawa

### TABLE OF CONTENTS

- Introduction
- Physical principles of the method
- Research equipment
- Calibration of devices for residual austenite control in elements after thermal processing
- Results of tests of the occurrence of residual austenite in bearing steel
- Conclusions
- Literature

### Introduction

While quenched steel with carbon above 0,6%, the temperature of the end martensite transformation is below zero, thus the transformation of austenite into martensite is incomplete and this remaining cooled austenite is called residual austenite.

Residual austenite is a steel structure which during cooling at martensite transformation temperature is not completely converted into martensite and remains unchanged at room temperature together with martensite.

The structure of residual austenite is metastable, during exploitation it may partially transform into bainite, whereas during quenching this transformation may be caused by the freezing out processing. The transformation of residual austenite into bainite is connected with volume change, whereas diminishing the content of austenite in martensite by 1% causes a 0,07% increase of its volume.

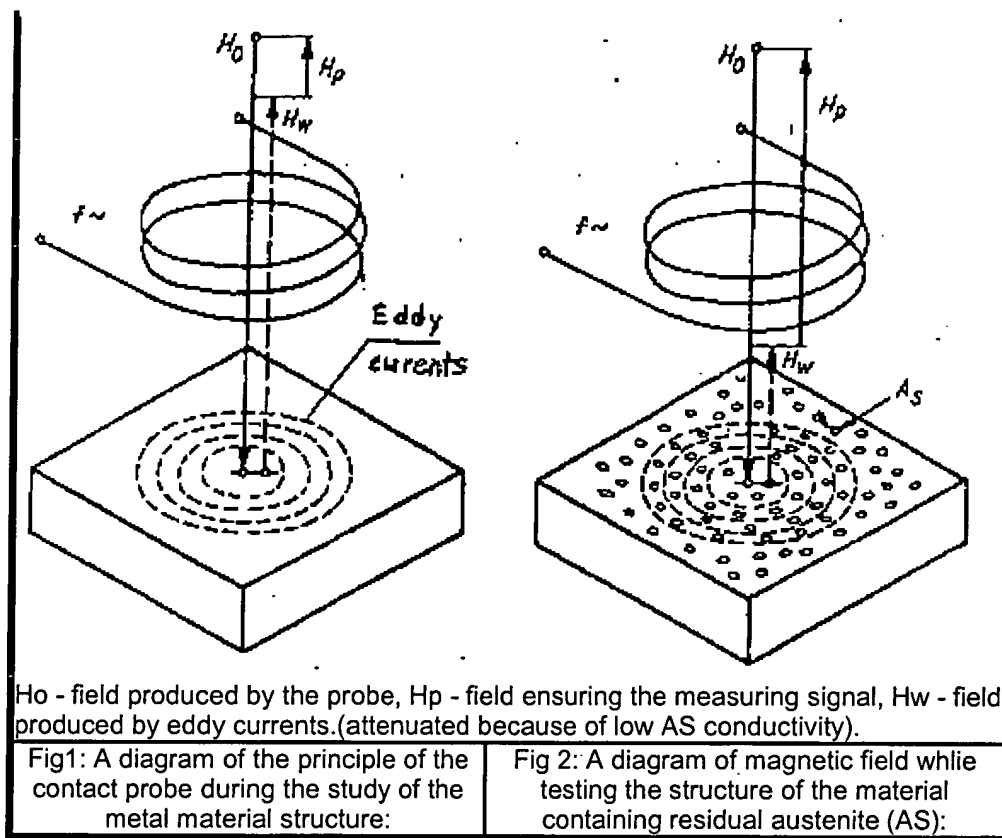
With regard to use residual austenite indicates defects in form of low hardness, but with regard to physical features it is characterized by low, with regard to martensite electrical conductivity and magnetic penetrability. The differences in electrical conductivity and magnetic penetrability of austenite with regard to martensite constitute the basis used for detecting residual austenite with the eddy current method. Detection and evaluation of the amount of residual austenite is possible using the roentgen diffraction method, microscopical observation in microsections, microhardness measurements (in this case detection of its significant amount - above 10%).

The eddy current method is used for the quantitative evaluation of residual austenite contents in the martensite structure.

### Physical principles of the method

The principle physical phenomenon of applying the eddy current method for evaluating the amount of residual austenite in the structure of quenched steel is magnetic induction, involving the influence of the changeable magnetic field on the studied area, found under the probe. In effect of such activity eddy currents in the studied area are induced, producing own magnetic fields; which following Lenz's rule are directed adversely to the induction field this decreasing its intensity (Fig.1)





The intensity of the magnetic field produced by eddy current is depended on electrical conductivity and magnetic permeability of the studied area. In case of a uniform structure, when the conductivity of the material is high, the intensity of the induced magnetic field is big and signal received by probe Hp is small. Structure defects decrease conductivity of the studied material, and then the intensity of the induced magnetic field is small and the signal received by the probe Hp is big (Fig.2). Low conductivity of austenite is a defects of the structure in case of residual austenite in the martensite structure, which with regard to the magnesite structure is as 1:5. Eddy currents produced in the studied area are subject to excitation in effect of small conductivity of austenite grains in the structure of the studied material.

## Research equipment

Eddy current devices for detecting residual austenite comprise:

- variable current generator with frequency controlled from average (KiloHertz) to high (MegaHertz),
- contact probe with constant location with regard to the studied, or material or external passage with appropriately converged field, with regard to the elimination of the influence of border conditions, which occur in case of controlling the object of finite dimensions,
- amplifier with controlled amplification with regard to the adjustment of the indication scope (output signals) to the control system and part segregation,
- decoder preparing the signal of measuring results to information and automatics indicators
- performance signal transferring threshold signals to segregation devices

Specification	WIROTEST 202	WIROTEST 12 FINISH
Frequency of magnetising current	2,5 MHz	10
Supply	220V 50Hz of batteries	220V 50Hz

Type of probe	Passage or contact	Passage or contact
Power supply	15 W	15 W
Thickness of controlled layer	100μ M.	100μ M.

Table 1. Characteristics of devices detecting residual austenite

The detection of residual austenite in fact requires average frequency, however for comparison reasons (reference) with a different recognized method, it is recommended to use high frequency, as with high frequency of eddy currents the penetration depth is comparable in the diffraction method and eddy current method.

Attention should be given in the fact, that penetration of eddy currents in residual austenite will be slightly deeper than in the martensite structure of steel, as austenite shows low electrical conductivity. The signal originating from the austenite structure will be amplified in effect of the influence of the structure found at greater depth. There will be no error as the method of measurement is comparable and the samples made for reference purposes will have the same structure as the studied part.

The application of high currents in case of bearing steel, has also a different practical aspect, the small penetration of eddy currents delivers a concentrated measuring signal from the surface of studied element, and the grinding burning occurs in the surface layer.

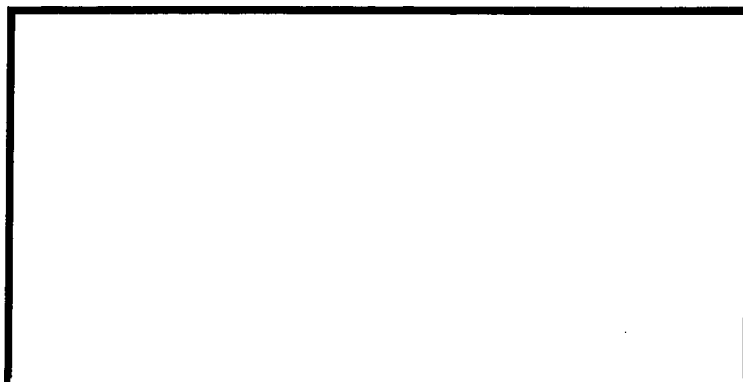
The indicated eddy current devices referring to the burning of the surface have an opposite sign to indications originating from the structure of residual austenite. During one control process grinding burning can be detected as well as residual austenite, with reference made to samples for determining limits of values allowed for residual austenite and the state of the surface layer after grinding.

For detecting and percentage evaluation of the participation of the amount of austenite in the quenched structure of hyper-eutectoidal steel, devices manufactured by IMP type WIROTEST 202 and WIROTEST 12 finish (Table 1.) are applied. These devices allow to detect and evaluate the content of residual austenite as well as form the signal for part segregation with austenite content above the allowed amount, as well as parts with grinding burning

### Calibration of devices for residual austenite control in elements after thermal processing

The determining of sorting limits of steel parts after thermal processing in order to eliminate these, which indicate exceeded allowed content of residual austenite, requires elements of identical shape and dimensions, as the studied parts, and with known content of residual austenite. Such elements serve to define the sorting threshold, during manual control as well as automatic.

It is known, the residual austenite is not a stable structure and after some time is transformed into a bainite structure, so elements used for calibrating sorting thresholds will be unstable, and thus unreliable. Thus special reference samples showing structure stability should be used.



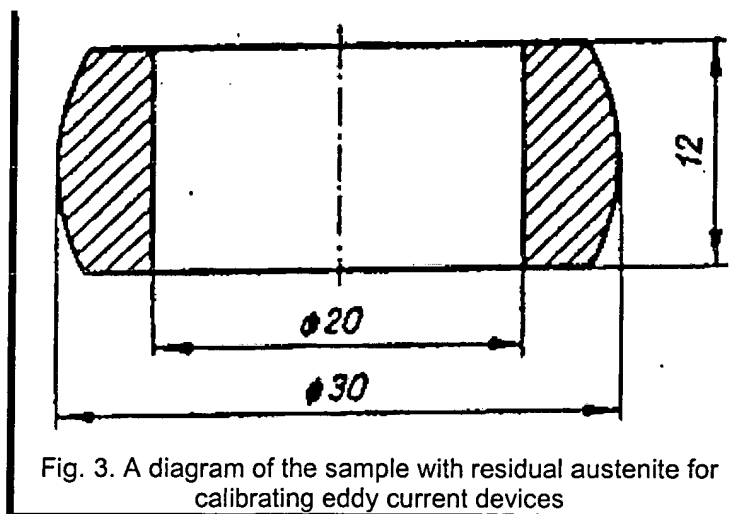


Fig. 3. A diagram of the sample with residual austenite for calibrating eddy current devices

Thus they have been replaced with elements with a martensite structure mixture fully transformed by the zero processing and mounted in openings with inserts of austenite steel (Fig.3). Thus prepared elements for calibration will be stable with time and will not cause any indication changes during exploitation.

The percentage share of the inserts made austenite steel in the martensite structure is referred to the visual field of the probe in the given location. Every probe after performance is given a characteristics, in which the visual field is given, determined using special devices defining the visual field at different distances from the tested object.

### Results of tests of the occurrence of residual austenite in bearing steel

Bearing elements made of bearing steel were subject to studies. External ring-type elements with an internal race of 20 mm diameter and 12 mm height (Fig.4) were subject to tests using the contact probe and internal volumetric ones. Results of tests are given in Table 2.

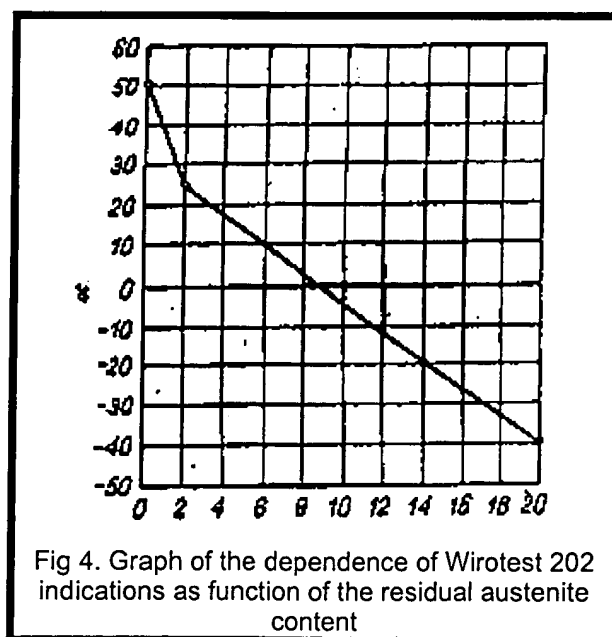


Fig 4. Graph of the dependence of Wirotest 202 indications as function of the residual austenite content

No	% content of residual austenite	Wirotest 202 indications
----	---------------------------------	--------------------------



1	0	50
2	5	25
3	8	12
4	10	0
5	11	-3
6	11	-4
7	12	-8
8	14	-20
9	16	-25
10	20	-35

Table 2. Results of tests of residual austenite in bearing rings

Segregation of bearings, with regard to residual austenite was performed with the aid of WIROTEST 202 and WIROTEST 12 finish. Selected rings with defined indications were subject to metallographic tests, in order to state whether residual austenite occurs, and then using the diffraction method, the percentage content of residual austenite.

The shown in Fig. 4 graph of the dependence of the WIROTEST 202 as a function of the residual austenite content, allows to evaluate the content of residual austenite in steel in the scope for 5 +/- 100%.

It should be emphasised, that further tests will allow to obtain a higher precision of detectability of residual austenite, especially within the scope below 5%.

## Conclusions

1. The eddy current method may be used for controlling the share of residual austenite in the structure of quenched hyper-eutectoid steel in the martensite.  
The application of WIROTEST 202 device with high frequency magnetic currents, will allow for simultaneous detection of parts with burns, which can occur during grinding.
2. The elaborated method of applying elements for calibration of devices composed of the body with a martensite structure, with elements made of austenite steel placed in it, allows to ensure calibration repeatability.
3. Simple service of control devices, easy automation of the control process allows for extensive application in part manufacturing processes.

## Literature

1. Luty W.: Modern views on nucleation of fatigue micro-cracks in rolling bearings; MOC IMP No 6, 1973
2. Suwalski L., Kucharski Z., Lukasik M., Luty W.: Utilised of Mossbauer spectroscopy for measuring residual austenite in bearing steel; MOC IMP No 67, 1985
3. Wyszowska J.: Kinetics of growth of the austenite grain; Issued by IMP 1971
4. Hepner H., Stroppe H.: Magnetic and induction metal tests; Issued by "Slask" 1972
5. Lampe J.: Preparing surfaces for radiological determining of residual austenite; MOC IMP No 47, 1980

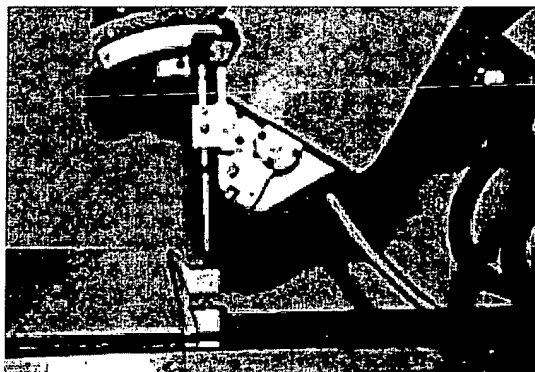
[\[Top\]](#)



Copyright © NDT.net, [info@ndt.net](mailto:info@ndt.net)

BEST AVAILABLE COPY

# X-Ray Diffraction



This technique is not widely known, but it allows detection of residual stress and the measurement of austenite remaining in metal samples.

Residual stress is due to thermal treatment, mechanical processes, welding and surface treatment that the pieces undergo during the manufacturing process. This type of stress permanently influences the piece's resistance, especially under strain, and often the cause of breaks that have no metallurgical justification. One example is given by the alterations in the surface tension induced by heat in grinding, easily detected with X Ray diffraction or with the Barkhausen Noise method.

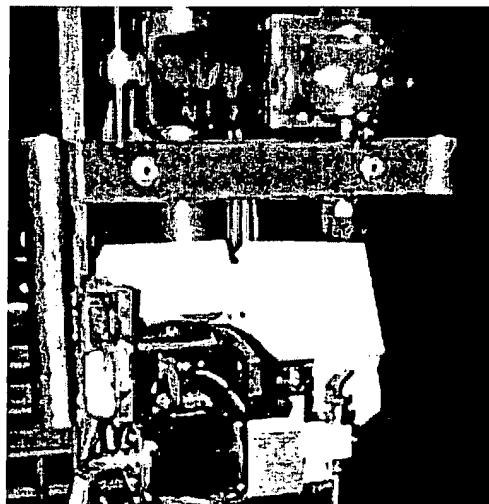
Even a small percentage of residual austenite (5%) can cause deformations that make the piece unusable. An example can be given with ball bearing tracks and injector pins for diesel motors. Detection of their presence can optimise thermal treatment.

2 Effe Engineering uses special equipment to measure residual stress and residual austenite, providing a thorough non-destructive analysis of samples of any dimension, so detection can be made directly.

Eng. Marconi, for example, has analysed the stress caused by casting and mechanical operations on the Stårebealt Bridge in Denmark.

*Main application of x-ray are:*

- definition of the quantity of residual austenite on bearings and parts of diesel motor injectors
- detection of residual stress on sprocket wheels
- detection of residual stress on car motor parts (cam axles, connecting rods, engine shafts, equalisers)
- detection of residual stress induced by deep drawing (household appliances, structural parts)
- detection of existing operational stress on gas conducts
- detection of operational stress on large tensioned structures
- measurement of efficiency of shot-peening and rolling of components subjected to stress
- detection of residual stress in castings (cast iron parts of tool machines and aluminium)



automotive components)

- detection of stress induced by (laser and electron) welding
- search for a correlation between residual stress and stress resistance of aluminium alloy car rims
- optimisation of working parameters for swarf removal to improve the stress resistance of mechanical components
- detection of residual stress on helicoidal and leaf springs
- search for critical zones after applying work loads (arms and aeronautics)

A particular application of XRD technology permits to quantitatively analyze the presence of different crystalline phases of the materials; this is possible by analysing a larger spectrum. In some cases it's very important to know the real phases because they could have a big influence on the functional characteristics of the material. It is also possible to check the composition of the powders for the HVOF plant.

